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FLOOD INSURANCE

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HYDRAULICS DIVISION

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FLOOD INSURANCE

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SYNOPSIS

Whenever a major flood occurs in any part of the United States, much discussion arises as to why facilities are not available for writing insurance to protect property owners against losses due to flooding of their property. This paper discusses methods of estimating flood frequencies, flood damage to individual properties, and the average annual flood damage that may be anticipated for any property subject to flooding. The question of errors of sampling involved in the statistical analysis of flood records, and spreading of the risk when issuing flood insurance policies, are discussed. Other special problems which are peculiar to the field of insurance are also considered, in order to evaluate the practicability of establishing a system of insurance against floods.

INTRODUCTION

This paper is based on a report prepared in 1952 for the Insurance Executives Association by the firm with which the writer is associated. Prior to that time the insurance business had not been able to devise a method of providing specific flood insurance coverage on a basis acceptable to the public and at the same time in conformity with sound insurance principles. Certain types of loss due to floods have customarily been included under various forms of insurance, particularly on property which is mobile in character and which presumably has a chance of being moved out of danger when a flood threatens. Standard fire insurance policies also cover losses due to a fire or conflagration which accompanies a flood. In general, however, the peril of flood presents peculiar problems with which the business of insurance has, to date, found no way to cope.

Following the disastrous floods of 1951, insurance underwriters began a re-examination of their traditional position respecting flood damage. A committee of fire insurance executives was appointed by Insurance Executives Association to study the problem of floods and flood damage. The engineering firm of Parsons, Brinckerhoff, Hall & Macdonald was retained to make a comprehensive study of the technical problems and mechanics involved in measuring the exposure of property to damage by flood. This paper outlines the results of the study and summarizes the conclusions reached by the Insurance Executives Association with respect to "flood insurance".

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The technical problems involved are presented herein from an engineering viewpoint. The methods of analysis are explained in general terms only, without including theoretical details, since much of the latter have been extensively discussed in the technical press and in the society publications. Various other matters which may have an influence on the determination of premiums for flood insurance policies are also briefly considered.

Magnitude of Flood Problem*

Data on Flood Losses

The principal source of information as to flood losses in the United States consists of data which have been collected by the U. S. Weather Bureau on a national basis since 1902. The Bureau has published estimates of the amount of damage caused by each flood, utilizing chiefly questionnaires to county agents, county and city engineers, postmasters, mayors and river observers. Individual letters are sent to industries and railways. Officials in charge of district centers of the Bureau sometimes check the returns from the questionnaires by reference to newspapers and estimates of other agencies such as the Corps of Engineers, and by occasional field inspection.

While the Weather Bureau flood statistics are the only available estimates of flood losses on a nation-wide basis, other agencies make estimates of damages for particular floods, or within limited areas. These include the Corps of Engineers in connection with authorized surveys for flood control; The Bureau of Agricultural Economics; The American Red Cross; and a few Federal, State and local agencies which collect flood loss data in areas of restricted scope or for special types of losses.

Evaluation of Flood Loss Data

The available nation-wide flood loss statistics are unreliable and inconclusive due to the methods of evaluation. The facilities for data-collection do not assure that the losses resulting from every flood will be recorded accurately, promptly and completely. Substantial losses either are not recorded or are recorded incorrectly. Hence the available national statistics must be used with the understanding that they are incomplete, are not strictly comparable from year to year or from place to place, and contain many gross inaccuracies in valuation of loss.

The inconsistencies involved in the methods formerly used for estimating flood losses have been recognized by the various Federal agencies, and should be largely eliminated in the future as the result of investigations of the Federal Inter-Agency River Basin Committee. This Committee issued a Report on Proposed Practices for Economic Analysis of River Basin Projects, in May 1950, which includes recommendations for the determination of flood damages and the benefits from flood-control works.

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* See references 1 and 2

Increases in Flood Losses

A summary of flood-loss statistics published by the U. S. Weather Bureau is given in Table 1. Examination of this table shows an apparent tendency for flood losses to increase in the later years of the record. As it is doubtful whether there has been any general increase in the frequency of occurrence of major floods in the last 50 years it seems apparent that the large increase in mean annual flood losses is due primarily to the greater exposure of property to flood damage, due to encroachment on flood-plains. "Floods which caused little loss in numerous drainage-areas in the early part of the period would cause severe losses if they were to recur with the same magnitude today" (Ref. 1).

T A B L E 1

FLOOD LOSS STATISTICS - U. S. WEATHER BUREAU

Loss of Property in the United States
1902 - 1949

Year (Ending June 30)	Property Loss $1000	Calendar Year	Property Loss $1000
1902-03	53,116	1924	16,980
4	6,545	25	9,922
5	11,000	26	23,470
6	400	27	347,658
7	15,576	28	44,614
8	8,250	29	68,099
9	49,134	1930	15,850
1909-10	21,239	31	2,810
11	7,772	32	10,295
12	77,586	33	36,679
13	171,388	34	10,361
14	17,952	35	127,130
15	14,131	36	282,549
16	26,124	37	440,740
17	27,330	38	101,100
18	7,867	39	13,834
19	3,164	1940	40,466
20	24,771	41	39,525
1920-21	28,647	42	98,506
22	52,060	43	199,733
1922-23	33,933	44	101,079
1923-24	29,814	45	165,797
		46	70,814
		47	272,328
		48	229,258
		49	93,932
Mean (1902-24)	31,264	Mean (1924-49)	110,161

TABLE 2

PROPERTY LOSS FROM FLOODS - U.S. WEATHER BUREAU STATISTICS - BY DISTRICTS

(VALUES IN THOUSANDS OF DOLLARS)

YEAR	GREAT LAKES	NORTH ATLANTIC	SOUTH ATLANTIC	EAST GULF	OHIO VALLEY	UPPER MISSISSIPPI	LOWER MISSISSIPPI	MISSOURI	ARKANSAS	RED	WEST GULF	COLORADO	PACIFIC	MISC.	TOTAL, U. S
1925	--	50	3 000	615	33	3 982	115	--	223	--	1 436	--	468	--	9 922
1926	19	137	--	37	5 524	5 436	42	1 434	8 938	155	301	447	--	1 000	23 470
1927	15 750	29 408	1	255	15 640	19 612	133 898	4 860	26 183	100 908	208	12	903	--	347 658
1928	--	2 105	8 382	2 428	10 279	1 174	7 820	6 715	4 349	153	75	100	1 032	--	44 612
1929	171	245	10 196	8 746	17 050	3 678	9 980	2 118	7 516	100	8 124	175	--	--	68 099
1930	36	--	--	466	7 042	15	530	14	213	3 616	924	--	--	2 995	15 851
1931	1	1 050	31	174	1	20	--	886	7	19	2	3	560	55	2 809
1932	1	25	191	615	288	88	1 841	451	2 528	516	3 522	13	217	--	10 296
1933	14	5 419	19	444	7 725	1 157	6 933	1 391	776	38	1 160	--	11 604	--	36 680
1934	--	142	240	13	928	1 023	--	1 906	18	640	422	22	5 008	--	10 362
1935	13 185	16 340	77	720	8 536	1 506	6 631	38 959	8 344	2 752	29 522	--	557	--	127 129
1936	9	146 034	2 391	1 240	122 296	313	55	109	817	16	8 376	--	892	--	282 548
1937	690	2 690	990	358	413 937	1 127	6 658	1 368	1 558	25	1 830	264	9 245	--	440 740
1938	240	37 068	455	1 655	4 481	3 659	1	4 333	2 202	755	6 003	257	39 990	--	101 099
1939	11	56	454	6 680	3 773	228	1 448	609	179	22	360	13	--	--	13 833
1940	--	2 519	5 034	5 496	8 077	199	--	1 759	1 332	12	7 622	180	8 236	--	40 466
1941	--	--	89	24	1 122	3 018	--	12 019	13 346	1 855	5 458	1 062	1 532	--	39 525
1942	153	22 321	608	155	16 546	5 592	475	22 511	6 576	2 205	12 489	3	8 871	--	98 505
1943	9 564	1	152	773	31 416	42 097	829	62 630	41 850	44	2 589	301	7 477	--	199 732
1944	130	--	1 927	2 660	806	27 031	1 550	44 616	11 171	1 676	8 938	575	--	--	101 080
1945	119	5 729	1 007	268	52 887	9 288	3 601	34 402	15 068	22 209	10 987	182	9 530	520	165 797
1946	251	8 500	172	2 963	10 914	8 642	4 407	8 305	1 792	1 434	15 967	--	7 367	100	70 814
1947	5 761	198	944	654	7 812	87 937	2 555	163 176	1 424	1 446	330	3	88	--	272 328
1948	20 270	12 467	1 372	3 122	16 871	2 905	5 390	31 489	18 721	220	4 604	1	111 826	--	229 258
SUM 24 Yrs	66 375	292 504	37 732	40 561	763 984	229 727	194 759	446 080	175 131	140 816	131 249	3 622	225 403	4 670	2 752 613
MEAN	2 766	12 187	1 572	1 690	31 833	9 572	8 115	18 587	7 297	5 867	5 469	151	9 392	194	114 692
% Of Total U.S.	2.4%	10.6%	1.4%	1.5%	27.8%	8.3%	7.0%	16.2%	6.4%	5.1%	4.8%	0.1%	8.2%	0.2%	100.0%

TABLE 3

AVERAGE ANNUAL FLOOD DAMAGE IN THE U.S.

Estimated by Corps of Engineers.

(From "Summary of Plans for Conservation and Development of the Water Resources of the United States". Pamphlet prepared in the Office, Chief of Engineers, Department of the Army. June 15, 1948.)

Drainage Basin	Damage Prevented by Existing Projects	Damage Remaining Under Present Conditions	
Atlantic Northeast	$ 10,934,000	$ 42,088,000	9.0%
Atlantic Southeast	13,062,000	19,162,000	4.1
Alluvial Valley of Mississippi River	212,847,000	34,899,000	7.5
Ohio River Basin	36,786,000	60,535,000	13.0
Great Lakes Basin	310,000	6,103,000	1.3
Upper Mississippi River Basin	10,140,000	52,756,000	11.3
Red River of the North Basin	45,000	2,391,000	0.5
Missouri River Basin	4,550,000	50,100,000	10.8
Southwestern Tributaries of Mississippi River	12,099,000	47,612,000	10.2
Gulf Southwest	7,014,000	52,935,000	11.4
Pacific Southwest	31,550,000	70,197,000	15.1
Pacific Northwest	4,194,000	27,331,000	5.8
	$343,531,000	$466,109,000	100.0%

Distribution of Flood Losses

The geographical distribution of flood-losses recorded by the Weather Bureau is indicated in Table 2.

Studies of flood damages have been made on most of the principal rivers of the United States by the Corps of Engineers of the U. S. Army. Overall estimates of the average annual damage for the entire country are given in Table 3, distributed by drainage basins. These estimates are considerably greater than shown by the Weather Bureau Statistics. They include both Direct Damage and Indirect Damage. While the distribution of losses shown by the Corps of Engineers differs to some extent from that indicated by the Weather Bureau statistics of Table 2, both estimates show that the Mississippi River basin, including all

tributaries, suffers fifty percent or more of the total losses for the entire country.

Kansas-Missouri Flood of 1951

As an illustration of the magnitude of damages which may result from a single flood, the great flood of July 9-13, 1951, in the Kansas-Missouri area is of particular interest. (Ref. 3) This flood was caused by abnormal meteorological conditions extending from the central part of the United States to the eastern part of the Pacific Ocean, resulting in excessive precipitation over a large area in the early part of July. Unusually heavy rainfall during the preceding two and one-half months had saturated the entire basin, so that when the cloudbursts of July 9-13 occurred, there was nothing to hold the runoff in check. The resulting peak discharge at Kansas City reached 510,000 cfs., which may be compared to 260,000 cfs. in the great flood of 1903, and an estimated 360,000 during what had previously been referred to as the "granddaddy of floods", in 1844.

But it might have been considerably worse. The discharge from this flood came primarily from the Kansas River Basin and the Osage River Basin in Missouri. Fortunately, the discharge in the Missouri River above Kansas City was comparatively low on July 13. It was estimated that, if the 1951 storm had centered a few miles north of its actual occurrence, it would have produced 676,000 cfs. at Kansas City, which is one-third greater than the actual 1951 discharge.

The total flood loss in the Kansas City District was estimated as $838,000,000; in addition the total agricultural damages in the basins of the Kansas, Osage and Lower Missouri Rivers were estimated as $194,000,000. There was great concentration of losses in the metropolitan area of Kansas City, which included not only direct damage by water but also fires caused by floating oil, severed gas mains and broken power lines.

For a number of years, the Corps of Engineers and the Bureau of Reclamation have been constructing a series of flood control reservoirs in the Missouri River Basin. This program had not been completed at the time of the 1951 flood. It was estimated that operation of the existing flood control projects in the Kansas City District during the 1951 flood prevented tangible damages of $292,000,000.

If all the flood control works proposed for the Missouri River Basin had been completed and in operation at the time of this flood, the crest discharge at Kansas City would have been about 150,000 cfs. less than the actual flood discharge, which would have reduced the stage about five feet, and would have substantially reduced the damages caused by the flood. Nevertheless, even with the completion of the program for flood control as proposed previous to July 1951, a repetition of the 1951 flood would cause large damages due to the unprecedented flood discharges.

From the standpoint of flood insurance, the 1951 flood demonstrates that even the most carefully prepared estimates of flood magnitude may be exceeded in a given locality; and that a single flood event may cause damages equal to several times the average annual flood losses for the entire country.

Probability of Floods

The basic problem in setting up flood insurance for a particular property is the determination of the average annual flood damages to which the property may be subjected. This may be subdivided into three parts:

a) The determination of the annual frequency (number of floods per year) or the average recurrence-interval (average interval in years between floods) for floods equal to or greater than a given intensity, as inferred from past records.

b) The estimation of the dollar value of damages caused to the particular property by a flood of a given intensity.

c) The determination of the mean annual flood damage for the property.

The present discussion covers the various methods which have been developed for estimating flood frequencies, and the reliability of the results to be expected from these methods.

Statistical Methods Used

Estimates of future flood occurrences must be based on past experience, modified by the anticipated effects of any changes in controlling conditions which may be expected to occur. It is impossible to forecast the actual flood intensities which will be experienced in any particular year. However, it has been possible to make estimates of the probability of occurrence of floods of various intensities, by statistical analysis of past records.

Statistical methods of considerable refinement have been used for many years in various fields, particularly in life insurance where the technical procedures have proved of great value. Somewhat similar methods were introduced into the field of hydrology about thirty-five years ago, and have received intensive study by many engineers within the past twenty years. However, there is a fundamental difference between the statistical methods used by engineers and those which have received general acceptance by statisticians.

In most statistical work, the data available for analysis run into a large number of items. For instance, life insurance calculations are based on the vital statistics of many thousands of individuals. But in hydrology and particularly in the study of flood records, the number of items available in any particular record are quite limited, seldom extending over more than fifty years and often being limited to twenty years or less.

Standard statistical methods involve assembling the data in the form of a "frequency distribution". The individual items are grouped according to their relative magnitudes, and a table is prepared showing the number of items the magnitude of which falls within certain assumed limits. When these groups are listed in order of magnitude, either increasing or decreasing, the result is called an "array", which may be plotted as a block diagram or "histogram" as shown in Fig. 1-a.

When a large number of items are available for analysis, a considerable number of blocks may be shown in the histogram, and frequently the tops of these blocks will form a more or less regular diagram. In

that case, a "frequency curve" may be plotted, which is a continuous curve approximately equivalent to the histogram, the area under the curve being the same as the area of the original diagram. An important function of statistical analysis is to determine the frequency curve that gives the best representation of the data, which is known as the "curve-of-best-fit". Such a curve can be used for making estimates of the frequency of occurrence of similar data in the future.

If the successive blocks of the frequency histogram are added together, starting from the smallest numerical value of the data (such as the smallest annual flood), a diagram of "total frequency" or "cumulative frequency" will be obtained (Fig. 1-b). This shows the total number of items in the original data which are equal to or smaller than a particular value. If a smooth curve is plotted to represent the block diagram, a "cumulative frequency curve" or "integral frequency curve" is obtained. This curve is generally referred to by engineers as a "duration curve", as it shows the total duration of time (or "percentage-of-time") that the data are equal to or smaller than a particular value. Mathematically speaking, the duration curve is the integral of the frequency curve. (See Ref. 12)

If the original data are limited in number, as is generally the case with flood statistics, a satisfactory frequency curve as described above cannot be constructed. But the same data can often be plotted as a duration diagram with a reasonable degree of regularity, so that a smooth duration curve can be fitted to it without too much difficulty. For this reason, the frequency curve itself is seldom used by engineers, whereas the duration curve has received extensive application to hydrological studies.

In many kinds of statistical analysis, it is found that the frequency curve obtained from the original data is closely similar to the so-called "normal frequency curve" or the "normal curve of error", which has had extensive use in the theory of probability.

The probability of occurrence of a flood of given magnitude may be expressed in a different way by giving the average number of years between occurrences of floods equal to or greater than the given flood. This is called the "recurrence interval". If P is the probability of occurrence in any year of a flood equal to or greater than a given magnitude, the recurrence interval of such a flood (expressed in years) will be 1/P.

There has been some confusion in technical literature regarding the use of the term "frequency" as applied to floods. Properly speaking, this term should be limited to its use by statisticians, as explained above. The duration curve gives the cumulative frequency, which is also the "probability" of occurrence of a given flood. Curves showing the recurrence-interval are sometimes described as "frequency curves", although this is an incorrect use of the word "frequency".

Selection of Flood Data

Several methods have been used to prepare an array of past flood events for use in estimating the probability of occurrence of floods in the future.

a) Annual Flood Method—The highest flood in each year is taken as the "annual flood". The resulting array consists of one item for each year of record. The smallest of the annual floods will have a recurrence-interval of one year and cumulative frequency of one per year.

b) Basic Stage Method—A certain rate of discharge is adopted as the minimum flood or "basic stage" for the given stream. All flood events in excess of this rate are tabulated to obtain the frequency array or duration curve. The usual method of selecting flood data is by use of the Partial Duration Series (plotting individual floods). The maximum flood discharge rate of each independent flood event during the period of record is tabulated in order of magnitude. Only those floods are used in which the maximum rate exceeds the "basic stage" adopted for the study. Generally, there will be more items in the resulting array than there are years of record.

While the Basic Stage method has been advocated by various hydrologists for certain types of study, it does not seem to be suitable in connection with flood insurance investigations. The partial duration series will generally include more than one flood in any particular year. If these individual floods are not far apart in date of occurrence, they should not all be included in the record. After one flood has occurred, a subsequent flood within a few weeks will not cause additional direct damage to the property unless the damage caused by the first flood has been at least partially remedied in the meantime.

It is reasonable to assume that not more than one flood loss claim would be paid on any insured property in any one year. On this basis, the proper method for selection of flood events will be the use of the Annual Floods. This method, due to the uniform process of selecting the individual flood items, gives a properly distributed sample and hence is better adapted to analysis by probability or statistical methods. Moreover, Langbein (Ref. 4) shows that the annual flood and basic stage methods give approximately the same results for recurrence intervals exceeding about five years.

Selecting the Curve-of-Best-Fit

Various methods have been advocated for plotting the flood-frequency curve (or the corresponding flood-duration curve), and for fitting a smooth curve to the observed data as plotted. Some of these methods are adaptations of methods extensively used in general statistical analysis; others are based on formulas developed specifically for use in hydrological investigations. (See Reference 5) It is beyond the scope of the present discussion to make a detailed analytical comparison of these methods.

While the advocates of some of the plotting methods maintain that their curves have a reliable mathmetical basis for determination of the curve-of-best-fit, it appears doubtful whether these claims can be fully substantiated. In the case of data which have a substantially symmetrical frequency distribution, the normal curve of error has been found by experience to give reliable results. The normal curve is a mathematical expression of the results of certain idealized experiments. When

applied to measurements of natural phenomena, however, the only proof of the scientific basis for the normal curve is that it gives a reasonably good fit to the recorded data. The same principle applies even more when dealing with non-symmetrical (skew) frequency distributions such as are commonly encountered in hydrological studies. In the opinion of the writer, the practical tests of reliability are: (1) which method gives the best representation of actual data; and (2) which method is most convenient to use.

The various methods of curve-fitting which have been proposed generally produce reasonably good results as applied to a given flood record, when used to express probabilities or recurrence intervals within the length of the record period, particularly if the record is not too short. For example, a 20-year record could be used to obtain a reliable estimate of a 10-year (10% probable) flood, regardless of which method is used for obtaining the probability curve. But when an attempt is made to extrapolate the flood-probability curve much beyond the recurrence interval covered by the record, considerable differences are revealed in the several methods. However, these differences are far outweighed in magnitude by the so-called "errors of sampling".

Errors of Sampling

In the language of statistics, a record of annual floods at a particular location is a "sample" of all floods which will occur at that location over a long period of years, the long-time record being known as a "population" and the individual recorded floods being items of the population. The items of the recorded sample may be analyzed by the various probability methods previously mentioned, and a smooth probability curve may be established as giving the best representation of the sample. But there is no assurance that a sample record covering the same length of time obtained during future years will produce the same probability curve. In a program of flood insurance, it is important to determine the extent to which the future record may differ from the available sample record.

Where a sample record can be expressed as a normal frequency distribution or probability curve, methods have been developed in the theory of statistics whereby the probable errors of future samples or the "spread" of the items in the future sample as compared with the available record may be reasonably estimated. To justify the use of these methods, it is necessary that the record conform with the Theory of Random Sampling.

From the statistical viewpoint, a flood record is a sample of an "infinite hypothetical population". Random sampling from a particular population tends to yield all possible different samples with equal frequency. This also involves the assumption that every member of the population is independent of its attribute (such as flood magnitude). In the case of floods, the theory requires that the magnitude of each item be independent of the items that precede or follow it. As already pointed out, this eliminates the use of the partial duration series for the selection of flood items.

Theoretical methods for estimating the probable errors of future

samples show that the relative magnitude of the errors decreases rapidly as the number of items in the record increases. For records of less than 20 years, the possible errors may be sufficiently large to appreciably affect any estimates of mean annual flood damages.

If the duration curve obtained from the given sample is represented by a straight line on probability paper as shown by Curve "A" on Fig. 2, the probable "spread" of the duration curves of other samples within certain confidence limits will be as shown on the diagram. The line marked "Coefficient of Risk = 5%" is the upper limit of the duration curves of all except 5% of the possible samples. In other words, there is a probability of only 5/100 that any future sample will be located above this curve. Similarly the line with Coefficient of Risk = 25% shows the upper limit of all except 25/100 of the possible samples. The original record has a Coefficient of Risk of 50%,—i.e., there is an even chance that any future record will be greater or less than the actual record. The curves for various Coefficients of Risk shown on Fig. 2 were obtained by use of a table prepared by L. R. Beard (Ref. 6, 7).

Regional Analyses of Flood Probabilities

In some areas, it may be necessary to prepare estimates of flood probabilities at locations where the available streamflow records cover only a short period of years. Such a record would not give a reliable estimate of future floods. But if there are longer flood records at other locations on the same stream or in adjacent drainage basins, these may be used to augment the local short-time record and increase the reliability of the resulting estimates. Numerous studies have been made to establish methods suitable for the correlation of flood records at different locations. While it is beyond the scope of this paper to describe such methods in detail, attention is called to two recent developments in this field:

L. R. Beard (Ref. 6, 7) has proposed a method for plotting flood records on logarithmic-probability paper and studying the relation of the median flood and the standard variation of the logarithms of the flood items (i.e., the "Variation Index" proposed by Lane and Lei in Ref. 8) to certain characteristics of the drainage basins, such as area, ground slopes, mean annual rainfall, etc. If such relationships can be established for a given area, the results may be applied to individual flood records to obtain a flood-probability curve which reflects the experience of the entire region included in the study.

W. B. Langbein (Ref. 9) has handled the same general problem by plotting the items of individual flood records as multiples of their respective mean flood values and comparing the resulting curves for all the records. He thus obtains a curve which represents the median of all of the available records, the results being expressed as multiples of the mean annual flood. This curve can then be applied to any particular location within the general area for which a value of the mean flood has been determined. (See also Ref. 10)

Each of these methods has as its object the preparation of a flood-probability curve for some particular location which will reflect the best information obtained from all the stations of record in the general

vicinity. The resulting accuracy will correspond to that which would be expected from the longest record available. But the errors of sampling connected with the latter would still have to be taken into consideration in evaluating the results of the study.

Changes in River Conditions

Where regulating works have been constructed on any river and have the effect of reducing the peak discharges of floods, the probability of occurrence of floods on the river will be affected. Any studies of flood-probability on such a river based on records prior to the construction of the regulating works would have to be revised before they would be useful in a subsequent program of flood-insurance. Obviously, the amount of detailed study required for preparation of flood-probability estimates at a given location will be appreciably increased if the discharge of the river is affected by flood control structures further upstream. Similarly, changes in watershed conditions, either in the past or anticipated in the future, which would cause increased flood discharge, such as removal of forests or the conversion of land to urban uses, must be given consideration in the determination of flood probabilities.

Studies by Government Agencies

Extensive studies of flood-probabilities have been made by certain government agencies, particularly by the Corps of Engineers of the U. S. Army and by the U. S. Geological Survey. The Corps of Engineers have made such studies on most of the important rivers in the United States, in connection with their investigations of river control projects. These studies have been carried out by the various District offices. The Water Resources Division of the U. S. Geological Survey has been making studies of flood-probability throughout the United States, in cooperation with appropriate departments of the local state governments. Up to the present, the studies have been completed for only a few states.

Different methods of analysis have been used by different government agencies in the study of flood-probabilities. In some cases, the same agency has used different methods at various times or in different offices. This is because no single method has up to the present been accepted by all hydrological engineers as the most suitable for such analyses.

Conclusions as to Methods of Curve-Fitting

Comparisons made by the writer between the various methods of curve-fitting discussed herein do not lead to any precise conclusions as to which method is the best for use in studies of flood-insurance. Within the time limits of the actual record, the several methods seem to be substantially equivalent as to results. When the curves are extrapolated beyond the highest floods of record, there is considerable variation in the results obtained.

Since one of the principal objects in preparing a flood-probability curve for insurance purposes is to permit the extrapolation of flood

frequencies beyond the time limits of the record, the question of the amount of possible error in the "sample" for these less frequent floods is of particular importance. Such errors may become relatively large, especially when the record covers only a few years. In fact, these errors of sampling far outweigh in magnitude any differences between the several types of theoretical probability curves discussed herein. Hence the selection of the most suitable method comes down to a question of convenience in application. Where studies of flood-probability have already been prepared for a particular location by some reliable method, they should be applicable to the determination of average flood damages, due consideration being given to all controlling factors which may be involved.

As will be shown later, a precise determination of the magnitude of floods with very low probabilities (the floods with very long recurrence intervals) is not of great significance for insurance computations, since these rare floods have only a slight influence on the value of the "average annual flood".

Flood Damages

The second part of the problem of estimating average annual flood damages to a particular property is the computation of the dollar value of damages caused to the property by a flood of a given intensity. This question must be considered in two parts:

1) To what depth will the property be inundated by the flood?
2) How much damage will be caused to the property when the water reaches such depth?

The first question involves the relation between "flood stage" or flood elevation and flood intensity; the second involves the relation between flood stage and damages, as related to the property in question.

The procedure for determining flood damages outlined in the following discussion is based on the experience of the Corps of Engineers of the U. S. Army, who have probably had more experience in this field than any other group, on account of the extensive studies which they have made for economic justification of the construction of flood control projects on important rivers throughout the United States.

Flood Stages as Related to Particular Properties

The work required for the preparation of diagrams of flood stage at a particular property, as related to the intensity of the flood, is outlined below. It is assumed that the analysis would cover a considerable area, such as a city or a portion of the river valley subject to flooding, in preparation for setting up a system of flood insurance.

1. Studies required for the general locality.

a) Topographic Maps. Contour maps must be available for the determination of ground elevations throughout the area. In the more important localities, maps of sufficient accuracy and detail can generally be obtained from government agencies, though it may be necessary to make additional surveys to fill in important details. It will generally be necessary to redraw or enlarge the existing maps, so as to summarize the topographic information, as follows:

1) An index map showing the entire area considered, divided into "damage reaches". A reach is a subdivision of the river valley which is sufficiently limited in extent so that the slope of the stream, the character of the banks and flood plain, the type of development of the flooded areas, etc., may be considered as constant throughout the reach and represented by average conditions.
2) Atlas Index Maps,—one for each damage reach; scale about one inch = 1000 ft. These will show the area covered by all of the Atlas Sheets for the reach.
3) Detail Atlas Sheets (scale about 1" = 400 ft.) on which all individual properties covered by the survey can be located in detail, together with information relating the property elevations to river stages through the reach. Ground elevations on the maps will generally be related to Mean Sea Level Datum (MSL).

b) River Stage-Discharge Curves. These show the elevation of the water surface at the gaging station for various intensities of discharge. At many important locations, stage-discharge measurements have been made by governmental agencies from which a "rating curve" may be prepared. However, there is not likely to be more than one such reference gaging station within the area under survey. Accordingly, it will usually be necessary to establish an additional gage for each reach, and take readings on these gages over a period of time covering at least moderate flood discharges, so as to prepare separate rating curves for each reach which may be extended to higher flood discharges by use of the reference gage record. If the river surface profile has an appreciable range of elevation within the reach, it may be necessary to subdivide the reach into smaller zones for each of which a correction factor will be applied to the gage height of the stage-discharge curve for the reach. The effect of this is equivalent to establishing a separate stage-discharge rating curve applicable to each piece of property within the reach.

In addition to the stage-discharge curves for the several reaches, all available information is collected as to the areas actually inundated by particular major floods. This information should be shown on the Atlas Maps and also used to check the stage-discharge curves. Elevations on the stage-discharge curves will be based on MSL. They should also be related to the stage reached by some particular flood, such as the maximum flood of record, so as to correlate damages to individual properties with flood stages, as explained below.

It should be noted that the preparation of the necessary maps and stage-discharge curves for a given locality may require a great amount of field surveys as well as office preparation, if such surveys have not already been made by other agencies, and the time required for such surveys and office work may extend over several months. The expense of such surveys must be incurred regardless of the amount of flood insurance subsequently issued in the area.

2. Studies required for particular properties.

a) Determination of MSL elevation of the property. This may be accomplished by simplified leveling methods, such as by use of a hand

level, starting from reference points previously established at various points throughout the reach. It is important to determine the "elevation of zero damage", or the flood stage at the property which must be reached before any material damage will occur. Frequently, this will be the elevation of basement window sills, or the ground floor door sill if there are no openings through the exterior walls of the basement. The zero damage elevation will also be referenced to the stage of the flood of reference by means of the stage-discharge curve for the reach, as explained above.

b) Classification of flood damages. Damages to property are classified as follows (see Ref. 2, 11):

1) Direct Losses. These consist of physical damage to property and goods, measured by present day cost of repair or the replacement in kind, and the cost of cleanup and for moving goods. The direct losses are generally subdivided as follows:

Residential. Homes and habitations (other than farm buildings), including furnishings.

Commercial. Buildings, fixtures, stock and merchandise.

Industrial. All manufacturing developments, buildings, machinery and stock.

Utility. All public or private utilities, such as electric and gas service, and transportation other than railroads.

Railroad. Track, structures, right-of-way, goods in transit or stored at terminals, supplies and equipment.

Agricultural. Farm houses, land, livestock; physical damage to standing or harvested crops.

Public. Government-owned utilities (such as sewers and water-supply), public and semi-public buildings and institutions.

2) Indirect Losses. These consist of value of service or use which is lost or made necessary by reason of flood conditions, not chargeable to direct loss. They include losses of business and wages, costs of relief and similar losses, both within and without the flood area, during the period of the flood and subsequent rehabilitation. The practice of the Corps of Engineers is to evaluate them as certain percentages of the various types of direct losses, these percentages being determined from available data studied by methods of sampling and rational analysis. It seems doubtful whether indirect losses of these types would be included in a program of flood insurance, although types of loss covered under "use and occupancy policies" might be included.

3) Depreciation Losses. The Corps of Engineers includes estimates of the loss of value and utility of real estate beyond that deductible from direct and indirect losses. The total depreciation equals the value before a major flood minus the value after the flood. Elimination of such losses by construction of flood-protection works is considered a proper credit for the economic justification of the works. However, it appears doubtful whether such depreciation losses would need to be considered in connection with flood insurance.

c) Estimates of Damages. The determination of the amount of damage that would be caused to the property by a particular flood stage is a matter of appraisal. The most reliable estimates of damage will be for floods of record for which the owner of the property has definite

records of loss sustained. If such records are available for two or three major floods, the damages for the smaller floods may be estimated by interpolation on a curve plotted through the known damage values.

In case the owner has no record of actual flood damage, the appraiser must make his own estimate. For important industrial or manufacturing plants, this will involve a detailed examination of the property and the installed equipment, and estimates of losses to be sustained by each piece of machinery or equipment and cost of cleaning up. Where the equipment can be salvaged after inundation, the loss will be the cost of repairs. For raw materials, finished stock, etc., similar estimates must be made. If there is reasonable expectation that part of such material could be removed to a safe location in advance of inundation, the loss would be correspondingly reduced.

Damage to buildings will generally be less than the total replacement cost of the building unless the type of construction is such as to result in total destruction, such as by undermining the foundation.

For certain types of structures, it may be possible to prepare typical diagrams showing amount of damage per 100 sq. ft. of ground floor area for various depths of flooding. Such diagrams could then be used to estimate the damage to any particular property, and thus reduce the amount of field work required by the appraiser. In some cases, the U. S. Engineer Corps has prepared similar diagrams for estimating damages to the equipment and stock of commercial establishments on the basis of percentage of the value of the material. However, unless these diagrams are based on reliable information, they should only be used where no other method of appraisal is feasible.

d) Dynamic Effects of Floods. The stage-damage estimates described above apply particularly to the inundation type of flood,—that is, where the water surface gradually rises until the property is partially or fully submerged. This type of flooding will occur where the slope of the flood-profile is moderate. But where the surface profile of the river is relatively steep or the flood waters are temporarily held back by obstructions, high velocity currents may be induced in the water flowing past buildings or other structures which may cause serious damages. A simple inundation may cause only partial damage to a structure, whereas the dynamic effect of rapidly flowing water may cause complete destruction. These effects are difficult to estimate in advance and can only be approximated by reference to past experience in a given locality.

In any insurance program, the types of loss to be covered (either direct or indirect) would have to be carefully defined in the policy.

Average Annual Flood Damage

Relation to Insurance

The average annual flood damage experienced by the owner of a particular property is the amount which the insurer would have to charge merely to pay losses, to which there would have to be added a "loading" to cover the expenses of the insurer. Thus the average annual flood damage, or average annual loss for an individual property, plus the expense loading would represent the premium which an insurer would have

to charge the property owner for protection equal to his estimated maximum probable loss.

Methods of Calculation

The determination of average annual flood damage to a particular property can be made by combining the results of three studies:

1) The diagram of flood stage vs. flood discharge, also called the "rating curve" of the gaging station corresponding to the given property.
2) The diagram of flood discharge vs. probability.
3) The diagram of flood-stage vs. property damage.

By methods shown below, these curves can be used to obtain a curve showing property damage in dollars vs. probability of occurrence. The procedure is best illustrated by a practical example, based on studies by the New England Division of the Corps of Engineers for typical industrial plants at Lowell, Mass., on the Merrimac River.

The stage-discharge curve applicable to the reach in which the properties are located is shown on Fig. 3. The ordinates of the curve are shown as Elevations above MSL; they are also indicated as stage in feet below an assumed "maximum probable flood" for which the discharge was arbitrarily assumed as 110% of the 1936 flood. (Any other flood could have been used, for reference purposes).

The discharge-probability curve adopted for this locality is shown on Fig. 4. By taking simultaneous points on the curves of Fig. 3 and Fig. 4, a curve of stage vs. probability is constructed as shown on Fig. 5. Typical points on this curve are listed below:

Discharge (1000 cfs.)	Stage Below Max. Prob. Flood	Probability %
180	1.3 ft.	0.3 %
100	12.0	4.3
50	19.6	60.0

Fig. 5 is applicable to all properties in the reach under consideration.

Information on estimated flood damage vs. flood stage for three industrial plants located in this reach is given on Fig. 6. The original data for these curves gave stage elevations in feet above MSL. These were referenced to the stage of the "maximum probable flood" before plotting on Fig. 6. The resulting curves, therefore, can be directly correlated with the curve of stage vs. probability (Fig. 5).

By combining the probability values of Fig. 5 with the damage values of Fig. 6, curves showing damage vs. probability are constructed, as shown on Figs. 7-a, 7-b and 7-c (for Coeff. of Risk = 50%). These curves show the probability of occurrence of flood damages equal to or exceeding various amounts. Thus, Fig. 7-a indicates that there is a probability of 0.20 that the damages will equal or exceed $180,000 in any year for property "A". Similarly there is a probability of 0.25 that the damages will exceed $140,000 in any year. Accordingly, there is a probability of 0.25 - 0.20, or 0.05, that the damages in any year will be between $140,000 and $180,000 or an average of $160,000. A probability of 0.05 indicates that during a period of 100 years, there will be an

average of five floods causing that amount of damage. Hence the average annual damage caused by that group of floods will be

$$\frac{5}{100} \times \$160{,}000, \text{ or } \$8{,}000.$$

A similar analysis will show that the total area under the damage-probability curve is a measure of the average annual damages caused by all floods which may be anticipated over a long period of years. In Fig. 7-a, as originally plotted one inch horizontally represents 10%, or a probability of 0.10; one inch vertically represents damages of $100,000. Hence one square inch of the diagram represents 0.10 x 100,000 or $10,000 average annual damage. The total average annual damages caused by all floods during a long period of time will, therefore, be the total area under the curve in square inches multiplied by $10,000. The resulting values for the three properties under consideration are shown in the following table:

Property	Area Under Curve (sq. in.)	Mean Annual Damage per sq. in.	Average Ann. Flood Damages
A	8.80	$10,000	$88,000
B	2.00	200	400
C	3.00	1,000	3,000

The figures in the last column of this table indicate the average annual damages for each property which would be expected from all future floods when averaged over a long period of years. They are an indication of the amount of money which would have to be set aside from premium payments each year to take care of losses over a long period of years, if there is no upper limit of the amount of damages to be paid in any one year.

If the amount of insurance on the property is less than the theoretical maximum damage (indicated by the ordinate of the damage-probability curve at 0% probability), the mean annual loss under the policy would be reduced. Thus, if the maximum loss in each of the three cases illustrated is limited to the loss experienced in the 1936 flood, the mean annual loss in each case would be reduced as follows:

Property	Mean Annual Loss Unlimited Policy	Reduction with Loss limited to 1936 Flood Loss		Relative Reduction of Mean Ann. Loss
		Area (sq. in.)	Loss	
A	$88,000	0.05	$500	0.57 %
B	400	0.42	85	21.2
C	3,000	0.02	20	0.67

It is evident that for properties which are subjected to loss during a considerable percentage of years, such as Properties "A" and "C", the mean annual loss will be only slightly affected by a limitation of the maximum loss covered by the policy. But a property, such as "B", which is located at such a high elevation that it is only damaged by

major floods would have its mean annual loss appreciably affected by a reduction in the maximum loss limit.

The relation between the mean annual loss and the maximum estimated loss is shown in the following table:

	Unlimited Policy		Policy Limited to 1936 Flood Loss	
Property	Max. Loss	Ratio of Mean Loss to Max.	Max. Loss	Ratio of Mean Loss to Max.
A	$1,000,000	8.8%	$755,000	11.6 %
B	90,000	0.45	30,000	1.05
C	40,000	7.5	32,500	9.2

This shows that the ratio of the mean annual loss to the maximum loss covered by the policy will be appreciably affected if the amount of insurance is made considerably smaller than the maximum possible flood damage. As this ratio is closely related to the annual premium rate of the policy, it is evident that the premium rate would have to be adjusted by an amount depending on the amount of insurance. This is because the mean annual loss is not reduced in the same relative proportion as the amount of insurance.

To investigate the relation between mean annual loss and maximum probable loss, the flood damage estimates for 54 industrial properties at Lowell, Mass., were examined. Values of mean annual damage for each property were calculated by the method outlined above. The maximum probable loss was generally estimated by extending the damage-probability curve to zero probability; this would normally correspond to the face value of the insurance policy.

The ratio between mean annual loss and maximum probable loss was computed for each property. As previously explained, this would be a factor in establishing the premium rate for a flood-insurance property. This ratio varied from 0.06% to 17.50%, for the 54 different properties, and was distributed as follows:

40% of the items have ratios less than 1%
55% " " " " " " 2%
87% " " " " " " 4%.

The properties which have low values of the ratio of mean to maximum loss in general have low values for the "probability of zero damage". This factor indicates the cumulative frequency of occurrence of floods which would cause damage to the property. A structure located at a relatively high elevation above the river would have a low value for this probability. Such a structure would be flooded only infrequently, so that its mean annual flood damage would be small compared with the maximum probable loss.

Somewhat similar results were obtained from studies of properties at Martin's Ferry, Ohio, located adjacent to the Ohio River.

This discussion indicates that there would be a great variation in premium rates for different properties, depending on the frequency with which they are damaged by floods. It does not appear likely that any

standard schedule of rates could be set up for industrial or commercial properties, but that the premium charge for each property would have to be determined by individual appraisal as previously described.

The studies also show that flood insurance on those properties on which such coverage is most needed could be offered only at a prohibitive premium because of the virtually certain loss, and therefore, for practical purposes, these properties would be uninsurable.

Capital Reserves

As already pointed out, if the portion of the annual premium set aside to cover losses is equal to the mean annual loss determined from the damage-probability curve for the property, the total amount collected in premiums over a period of years should be sufficient to pay all losses incurred during those years. This is only true when losses are averaged over a considerable length of time. It does not eliminate the possibility that the maximum possible flood may occur in <u>any</u> year. Unless the underwriter has set up reserve funds sufficient to pay such maximum loss at any time, the financial stability of the insurance program would be jeopardized.

Thus, for Property "A", the maximum probable loss is estimated as about $1,000,000; while the mean annual loss is about $88,000. If a reserve fund of at least $1,000,000 is not set aside, the insurance would be financially unsound even if the premiums allow for an average annual loss of $88,000.

This situation applies to all the insured properties in a particular area. Consequently, the total capital reserve required for any general area would be equal to the sum of the maximum estimated losses of all the insured property in that area. If the face value of the policies is less than the maximum losses, the reserve must equal the sum of the face values of all of the policies.

The basic reason why such a large reserve is necessary is because a major flood will cause damage to all insured properties located within the area affected by the river in question. In other words, there is no way by which the total risk may be reduced by spreading it over a large number of properties when those properties are all located in the same general flood area. In this respect flood insurance differs materially from fire insurance. Under normal conditions, only a small proportion of insured properties in a particular city suffer damage by fire in any one year, so that the risk of loss can be spread over a large number of policies. It is only in the case of a catastrophe, such as the Chicago fire of 1871, that a large number of properties are damaged by fire at one time. On the other hand, every major flood may be considered a catastrophe since it would result in damage claims from all insured properties within the affected area.

Spreading the Risk

If the insurance program is placed in operation in widely separated sections of the country, it is probable that some beneficial effect of "spreading the risk" may be accomplished. This is because major floods do not occur in all parts of the country in the same year. The

effect on an insurance program would be somewhat similar to the "Diversity Factor" of an electric power company, as a result of which the total installed generating capacity in the power plant does not have to be as great as the total installed load capacity of all motors or other types of electrical equipment which is served by the utility.

To determine accurately the "diversity factor" of floods throughout the United States by a study of the streamflow records alone would be a tedious and involved task. However, a qualitative analysis of the problem was made by examining the flood loss estimates of the U. S. Weather Bureau. That agency has made a practice for a considerable number of years of assembling data on flood damages throughout the United States, publishing the results annually by drainage basins. While the published results do not pretend to give an accurate estimate of all flood losses in each year, it is believed that they provide a qualitative picture of how such losses are distributed in different parts of the country. An analysis of these statistics should give some indication of the possibility of spreading the risk of simultaneous flood losses in different parts of the country.

The data used in this study included records for the years 1925 to 1948, incl. (See Table 2). The country was divided into 13 drainage basins, and the annual flood damage (in thousands of dollars) was summarized each year for each of the basins. The total damage loss for the entire country was given in each year. These total losses were arranged in decreasing order of magnitude, and plotted (Fig. 8) on arithmetic-probability paper as Curve "A".

The damage statistics for each of the basins were then analyzed separately by arranging the items in decreasing order of magnitude, thus forming a "duration tabulation" for each basin. The successive values of these tabulations for all of the basins were then added together, thus deriving a tabulation of the sum of the greatest losses for all the basins, the sum of the second-largest values, etc. The resulting tabulation was plotted as Curve "B" on Fig. 8, thus obtaining a "sum of the duration curves" of the individual basins.

Examination of Fig. 8 shows that Curve "A" (the duration curve of annual totals) encloses the same total area as Curve "B" (the sum of the duration curves),—or rather the two areas would be the same if the horizontal scale were arithmetic instead of probability. This is obvious, since the area under each curve is the average total annual loss for the entire country. (Ref. 12) But it is noticeable that the upper end of Curve "A" has much shorter ordinates than the corresponding portion of Curve "B". Obviously this is because the maximum damage items of the different basins do not occur in all the basins in the same year.

This effect is also shown in Table 4, which gives the losses of the seven more important basins for the five years in which greatest total losses for the entire country occurred. In three of these five years only one of the seven basins experienced its own maximum flood loss. In no year did more than two basins have their maximum losses.

Table 4 shows that in 1937, the year of maximum total flood losses for the entire country, these losses amounted to $440,740. On the other hand, the sum of the maximum losses in all of the separate drainage

T A B L E 4

FLOOD LOSSES FOR SELECTED BASINS

(U.S. Weather Bureau Statistics)

(Values in $1,000)

Basin	1937	1927	1936	1947	1948
N. Atlantic	2,690	29,408	146,034*	198	12,467
Ohio Valley	413,937*	15,640	122,296	7,812	16,871
Upper Mississippi	1,127	19,612	313	87,937*	2,905
Lower Mississippi	6,658	133,898*	55	2,555	5,390
Missouri	1,368	4,880	109	163,176*	31,489
Red River	25	100,908*	16	1,446	220
Pacific	9,245	903	892	88	111,826*
Total U.S.	440,740	347,658	282,548	272,328	229,258

* - Maximum loss for basin

basins amounted to $1,272,382. The ratio of 440,740/1,272,382 is 34.7%. That is, the total losses were only about 35% of what they would have been if the maximum floods had occurred in all the basins in the same year. From this it might be concluded that the reserve set aside to cover major flood losses in any particular basin could be reduced by 65% if the insurance program covered the entire country and was not limited to a particular basin. Due to the approximate nature of the original loss data used in this study, the results stated must be considered as being only qualitative; but they do indicate that a benefit would be obtained by spreading the risk over a large portion of the country.

It is important to note that this question of spreading the risk applies only to the maximum flood leases, and does not affect the mean annual loss for any property. The total flood loss for the entire country is not reduced in any year, even if the insurance program covers the whole country. But the risk of experiencing a major loss in one region is reduced by the fact that other regions will not be subjected to maximum damages in the same year. The practical effect of a wide coverage by insurance, therefore, would be to reduce the amount of capital reserve required to cover large losses in particular years.

Effect of Errors of Sampling

The above discussion of mean annual damages and maximum losses was confined to the determination of such losses on the basis of available flood records. As previously indicated, however, there is a possibility that floods in the future will show a different distribution as regards probability of occurrence, due to the "errors of sampling".

These errors will result in appreciable differences in estimates of mean annual flood damages.

By using the methods for estimating the range of error in future records previously outlined, the discharge-probability curve of Fig. 4 was corrected to show discharges having a "Coefficient of Risk" of 5% and 25%. (The original record has a Coefficient of 50%). Similar curves were plotted on Fig. 5 to show the effect of possible errors in the record on the stage-probability curve. With these modified probability curves, the damage-probability relations for properties "A" and "C" were redrawn, as shown on Figs. 7-a and 7-c.

It is apparent that the errors of sampling will have a large effect on the mean annual damage for each property, as follows:

Property	Mean Annual Damage		
	Coef. of Risk = 5%	Coef. of Risk = 25%	Coef. of Risk = 50%
A	$170,200	$112,400	$88,000
C	4,200	- - -	3,000

Evidently, there is no direct relationship between the Coefficient of Risk and the mean annual damages, except that the damages will increase as the risk decreases. The degree of risk which should be tolerated in setting up an insurance program is a matter of judgment. It is obvious that some consideration must be given to this factor when establishing premium charges on particular policies. It might be taken care of by a suitable increase in the capital reserves.

Minimum Insured Losses

It may be advisable in some cases to establish a minimum amount of damage which will not be covered by insurance, but which must be carried by the owner, similar to the "minimum deductible" clauses of automobile policies. Such a clause might be particularly suitable if the policy covers goods or stocks in storage, so as to give the owner an incentive to remove as much of the material as possible to a safe place in advance of the flood. If such a provision is included in the policy, it would have the effect of cutting off the lower part of the damage-probability diagram as shown on Fig. 7-a. The mean annual damage would also be reduced, being equal to the remaining portion of the diagram above the minimum loss line.

Flood Forecasting

Forecasting of floods on the more important rivers has been carried out by the U. S. Weather Bureau for many years, the extent and reliability of the forecasts having appreciably increased in recent years.

The short-range forecasts for one to fifteen days are of particular significance in connection with flood insurance. The value of these forecasts lies in their timeliness, so that property owners will receive warning of impending floods as far as possible in advance of the actual arrival of the flood waters.

Flood damages may be reduced in many cases by emergency measures based upon flood-forecasting. (Ref. 1) The more important measures are:

1) Removal of goods above the expected flood-stage by means of evacuation from the flood-zone or by raising them to a higher elevation in the same building.
2) Protection by treatment of immovable goods so as to render them less subject to damage from water and silt, and from floating objects.
3) The readjustment in schedules of business operations so as to minimize interruption in operations.
4) Erecting dykes, bulkheading doors and windows, etc.

An accurate and timely forecast is essential to the accomplishment of any of these measures, the necessary period of the warning varying with the measures to be taken.

Since 1903, estimates of the magnitude of savings resulting from flood-forecasts have been made by the U. S. Weather Bureau. For the years 1903-1937, it was estimated that the average annual saving amounted to $8,500,000. (Ref. 1) These savings have been increased in more recent years, largely through extension and development of the forecasting service. As of 1948, it was estimated (Ref. 13) that the average annual flood loss of the entire nation was $225,000,000; and that this loss would have been at least $25,000,000 greater if the flood-forecasting service were not in operation. While these figures are admittedly very approximate, they give some clues to the economic significance of forecasting.

If flood insurance were to be established in this country, it would doubtless be greatly benefited by an efficient forecasting service. However, there seems to be some doubt as to how much reliance should be placed on such benefits. Under present conditions, the following questions remain to be answered:

1) If the property owner fails to take due advantage of the forecast by delaying to take the necessary precautions or neglecting them entirely, can the insurance company refuse to indemnify him for part or all of his losses under the policy?
2) How can the insurance company be sure that the flood forecast will be reliable or will be issued in time so that precautionary measures can be taken by the assured?

Special Problems

Types of Floods

From an insurance viewpoint, floods may be classified as follows:

1) Simple Floods. Any flood in which the rise in the river stage is directly caused by excessive rainfall over the drainage basin upstream without any contributary factors such as backwater from downstream obstructions, ice gorges, dam breaks, etc.

2) Tidal Floods. Caused primarily by excessively high tide backing up into portions of rivers adjacent to the seacoast. They may be of special significance along coasts subject to hurricane winds. The crest

height of a moderate flood may be increased by tidal effect if the peak discharge in the river coincides with the normal time of high water.

3) Wind Floods. These would occur on a stream discharging into a large body of water with a long free sweep for the wind. A strong wind blowing steadily for some length of time may raise the water level considerably, causing backwater effect in the river. This type of flood is probably of minor importance.

4) Backwater Floods. Resulting from a rise in the water level of the river at some point downstream, such as would be caused by a flood in a tributary, which causes the water surface in the river to rise for some distance upstream.

5) Accidental Floods. These may be caused by the rupture of a dam upstream, with consequent sudden release of stored water. The resulting flood would be further increased if the rupture occurred at the time of heavy rainfall on the watershed. Their frequency of occurrence cannot be estimated; but the possibility of such floods should be considered if any weak or poorly designed storage structures are located upstream. Another type of accidental flood might be caused by improper operation of river control structures.

6) Ice Jams or Gorges. On some northern rivers, temporary dams are often formed by ice accumulating in the river and released during the spring thaw. These will cause backwater upstream, and flood discharges downstream if the dam breaks suddenly. They are often accompanied with simple flood discharge due to heavy rainfall, or excessive snow-melt on the watershed.

7) Snowmelt Floods. On many rivers, the normal spring floods are increased in intensity by melting of the snow cover over the watershed. Some of the major floods on the northern rivers are caused primarily by this factor.

8) Overland Floods. Certain areas which normally would not be considered as located in a flood-plain may be subject to damage from heavy rainfall flowing over steep ground slopes in the form of "sheet runoff". There is considerable doubt whether this condition should be classified as a "flood" properly speaking, or whether it is a case of direct damage by rainfall.

10) Mud Flows. These have frequently occurred in the semi-arid areas of the Southwest, where steep mountain canyons discharge onto a relatively flat plain. A cloudburst in the mountains may cause a sudden discharge of water down the canyon, carrying with it large volumes of mud, gravel, stones and even large boulders. This debris will be carried out onto the "alluvial fan" at the mouth of the canyon. Any structures located on this fan in the vicinity of the canyon may be seriously damaged by the debris, even though the discharge of water might not be sufficient to cause appreciable damage by itself.

Some of these types of flood are difficult or impossible to forecast from a probability standpoint. In a flood insurance program, it would doubtless be necessary to place certain limitations on the types of floods which would be covered by the policy issued on any property.

Effect of Insurance on Land Use

If insurance is issued to cover a property subject to the risk of occasional flooding, the owner of the property may be inclined to increase the use of the property on the basis that, if a flood comes, the additional loss which he will suffer will be compensated by the insurance company. The effect is similar to the stimulation in use of land which is protected from flood damage by construction of a reservoir upstream. Even without the stimulation of insurance, there may be a tendency toward encroachment of buildings and other structures on the flood-plain, in areas which are flooded only at intervals of ten or twenty years. Such encroachments will generally further increase the probability of flooding, due to reduction of the natural stream channel area.

If insurance has been issued to cover structures already located within the flood-plain, the owner may decide to change the type of use of the structures, with consequent increase in possible flood damage. This condition might be taken care of by making an annual inspection of the property and, if necessary, increasing the premium charge to correspond with such increased risk.

The uneconomical development of land subject to periodic inundation might be controlled by the fact that insurance premiums on such property would necessarily have to be relatively high. Hence, there would be a tendency to eliminate properties of that type from the insurance program.

Effect of Protective Works

Where flood-control works have been constructed in a particular area, the risk of damage to properties so protected will be reduced. The degree of such reduction will depend to a considerable extent on how the works are operated during any particular flood. While the works may be designed on certain assumptions as to manner of operation, there is no guarantee that they will always be operated in accordance with those assumptions. If insurance is issued on the basis of those assumptions, the insurance company would have to assume the additional risk involved in possible changes in the operating program.

Levees are designed to protect the adjacent property from floods up to a certain magnitude. If the levee is not properly maintained, it may be ruptured by a flood of lesser magnitude. This possibility may involve an additional risk to be carried by the insurance company.

Where flood-control works have been constructed on a river, the property owners in the valley downstream may feel a false sense of security by assuming that the degree of protection from which they benefit is greater than that actually provided in the design of the works. This may result in the increased use of land which is still unprotected, and greater risk of damage from floods.

Psychological Factors Affecting Insurance

Certain considerations which appear to be particularly applicable to flood insurance may be described as "psychological factors":

1) Prospective customers whose property is subject to most

frequent flooding would be most interested in obtaining insurance, whereas it would be relatively difficult to sell insurance on any property which has not been inundated for a considerable number of years. Thus, the most profitable business from the standpoint of the insurance company would be the most difficult to obtain.

2) There would be great interest in an insurance program immediately after the occurrence of a major flood. As time passes on, however, this interest may gradually fade away; and if the flood is not repeated for a number of years, the property owners previously affected may eventually decide not to renew their policies. This might have a serious effect on the ability of the company to build up a reserve to take care of future losses.

CONCLUSIONS

The conclusions reached in this study may be briefly presented by quoting from the report of the Flood Committee of the Insurance Executives Association, adopted May 15, 1952:

"To the experienced insurance mind, the flood peril presents the same sort of unpredictable widespread devastation and destruction that we associate with modern war damage, and the same considerations which prompted the business of insurance to refrain from assuming liability for war damage to property on land during World War II. . . . If it could be established that the risk of loss by flood is a proper subject for insurance, that specific flood insurance could be written on a sound basis, and that the public would purchase specific flood insurance at indicated rate levels, it is obvious that companies generally would desire to engage in this field. Because of the virtual certainty of the loss, its catastrophic nature, and the impossibility of making this line of insurance self-supporting due to refusal of the public to purchase such insurance at the rates which would have to be charged to pay annual losses, companies generally could not prudently engage in this field of underwriting. It is our considered opinion that insurance against the peril of flood applicable to fixed property cannot successfully be written and that any specific promise of indemnity for loss by flood must therefore be regarded as in the nature of a subsidy or relief payment, which are quite outside the scope of private business and of insurance. . . . Since for the reasons outlined private underwriters cannot undertake to provide specific flood indemnity as an insurance venture, it follows that Government likewise could not undertake to provide specific flood indemnity by means of insurance. There is no reason to believe that the Government would encounter fewer obstacles to such an undertaking than private insurers. . . . . As a long-range program, it appears that an accelerated flood control program supplemented by such relief payments as are necessary on account of flood damage would be more in the interest of the public than a program of so-called "flood insurance" which would not be self-supporting."

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REFERENCES

1. Economic Aspects of Flood Forecasting - Gilbert F. White Trans. AGU, 1939, pg. 218.

2. Human Adjustment to Floods - A geographical approach to the flood problem in the U. S. Gilbert F. White. PhD Thesis, Univ. of Chicago, 1942. Published as Research Paper #29, Dept. of Geography, Univ. of Chicago, 1953.

3. Address to A.S.C.E., New Orleans, March 7, 1952, by Brig. Gen. C. H. Chorpening, Asst. Chief of Engineers for Civil Works.

4. Annual Floods and the Partial Duration Series - W. B. Langbein. Trans. AGU, 1949, pg. 879.

5. Review of Flood Frequency Methods - Final Report of the Subcommittee of the Joint Committee on Floods (Hydraulics Division). Proceedings ASCE, Dec. 1951; Separate No. 110.

6. Estimation of Flood Probabilities - L. R. Beard. Unpublished Manuscript, May, 1950.

7. Flood Frequency Analyses - L. R. Beard; Office of Chief of Engineers, Civil Works Bull. 51-1; 8 January, 1951.

8. Stream Flow Variability - E. W. Lane and Kai Lei. Trans. ASCE, Vol. 115, 1950, pg. 1084.

9. U. S. Geological Survey; Water Resources Division; Handbook for Geologists.

Chap. I	Instructions for Flood Frequency Compilations (1949).
Chap. VIII	Flood Frequency Analyses (1950).

10. Regional Flood Frequency - Tate Dalrymple. Highway Research Board (National Resources Council); Research Report No. 11-B; 1950; Surface Drainage.

11. Evaluations of Flood Losses and Benefits - Edgar E. Foster. Trans. ASCE, Vol. 107, 1942, pg. 871.

12. Duration Curves - H. Alden Foster. Trans. ASCE, Vol. 99, 1934, pg. 1213.

13. A Modernized Flood Forecasting Service - Eng. News-Rec. December 9, 1948.

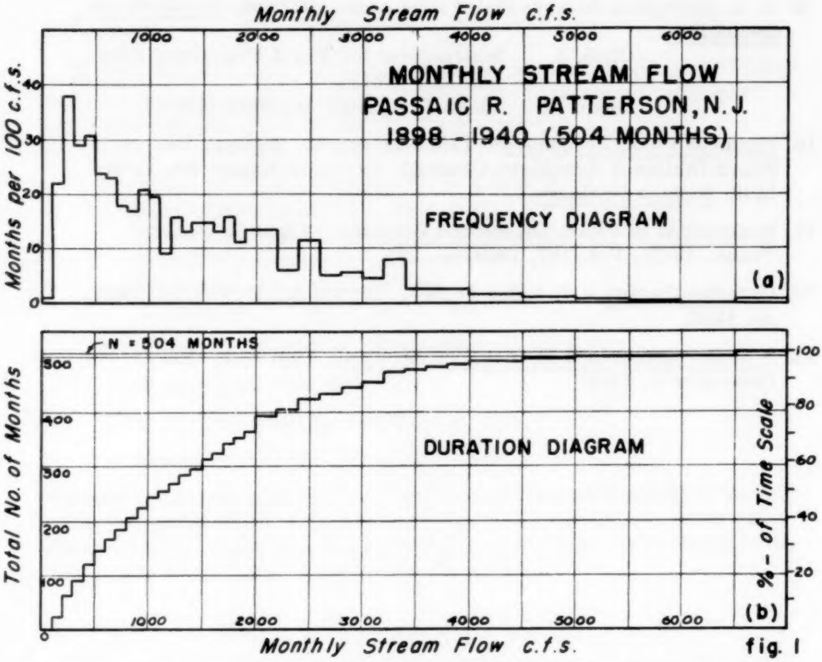

Monthly Stream Flow c.f.s.
MONTHLY STREAM FLOW
PASSAIC R. PATTERSON, N.J.
1898 - 1940 (504 MONTHS)
FREQUENCY DIAGRAM
Months per 100 c.f.s.
(a)
N = 504 MONTHS
DURATION DIAGRAM
Total No. of Months
% - of Time Scale
(b)
Monthly Stream Flow c.f.s.

fig. 1

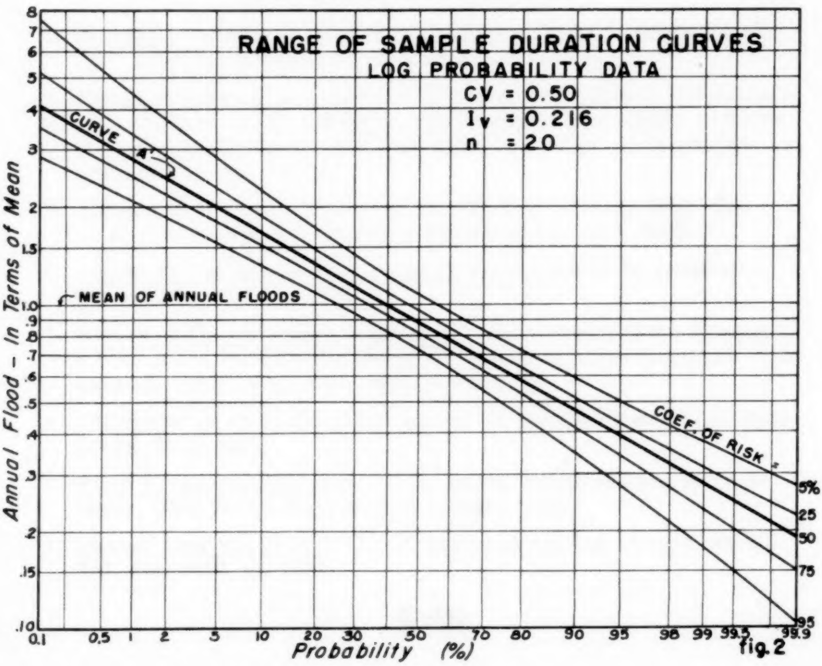
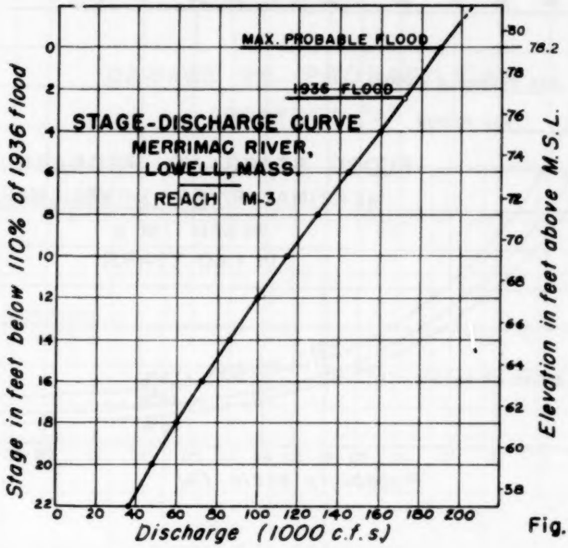
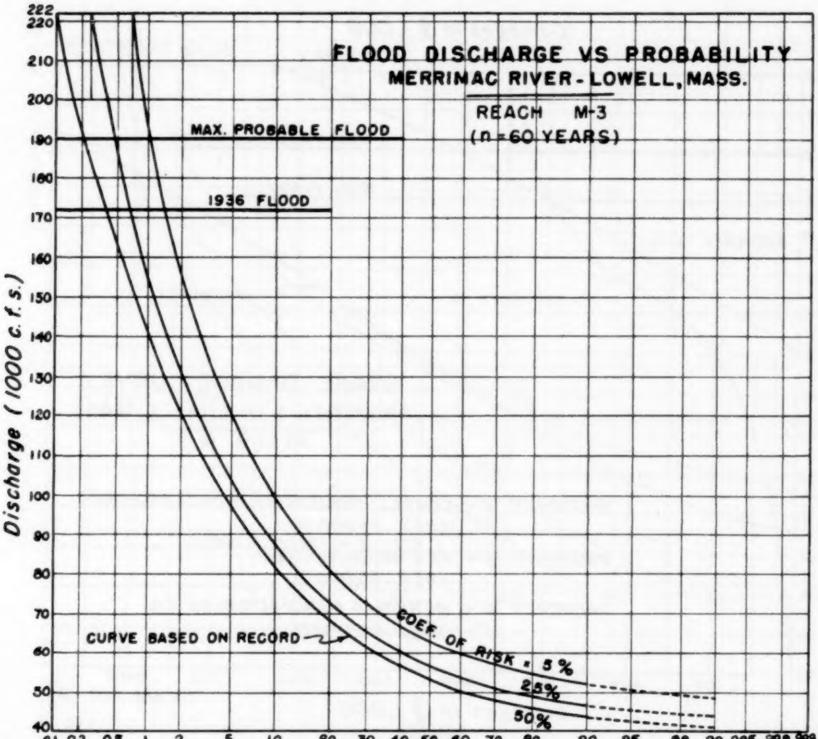

RANGE OF SAMPLE DURATION CURVES
LOG PROBABILITY DATA
CV = 0.50
Iv = 0.216
n = 20
CURVE "A"
MEAN OF ANNUAL FLOODS
COEF. OF RISK =
5%
25
50
75
95
Annual Flood - In Terms of Mean
Probability (%)

fig. 2



STAGE-DISCHARGE CURVE
MERRIMAC RIVER, LOWELL, MASS.
REACH M-3
MAX. PROBABLE FLOOD
1936 FLOOD
78.2
Stage in feet below 110% of 1936 flood
Elevation in feet above M.S.L.
Discharge (1000 c.f.s.)

Fig. 3



FLOOD DISCHARGE VS PROBABILITY
MERRIMAC RIVER - LOWELL, MASS.
REACH M-3
(n = 60 YEARS)
MAX. PROBABLE FLOOD
1936 FLOOD
CURVE BASED ON RECORD
COEF. OF RISK = 5%
25%
50%
Discharge (1000 c.f.s.)
Probability (%)

Fig. 4

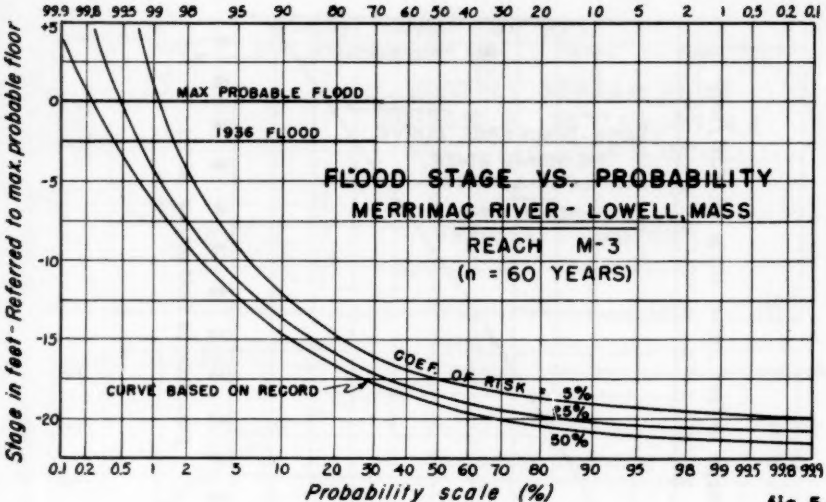

FLOOD STAGE VS. PROBABILITY
MERRIMAC RIVER - LOWELL, MASS
REACH M-3
(n = 60 YEARS)
MAX PROBABLE FLOOD
1936 FLOOD
CURVE BASED ON RECORD
COEF. OF RISK = 5%
25%
50%
Stage in feet - Referred to max. probable floor
Probability scale (%)

fig. 5

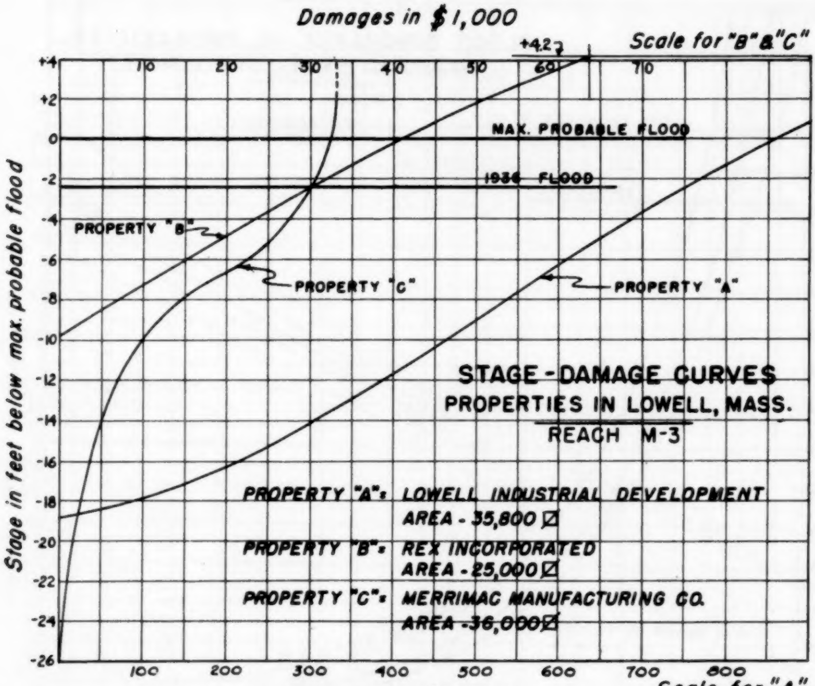

Damages in $ 1,000
+4.2
Scale for "B" & "C"
MAX. PROBABLE FLOOD
1936 FLOOD
PROPERTY "B"
PROPERTY "C"
PROPERTY "A"
STAGE - DAMAGE CURVES
PROPERTIES IN LOWELL, MASS.
REACH M-3
PROPERTY "A": LOWELL INDUSTRIAL DEVELOPMENT
AREA - 35,800 ☐
PROPERTY "B": REX INCORPORATED
AREA - 25,000 ☐
PROPERTY "C": MERRIMAC MANUFACTURING CO.
AREA - 36,000 ☐
Stage in feet below max. probable flood
Damages in $ 1,000
Scale for "A"

fig. 6

DAMAGE VS. PROBABILITY

PROPERTY "A"

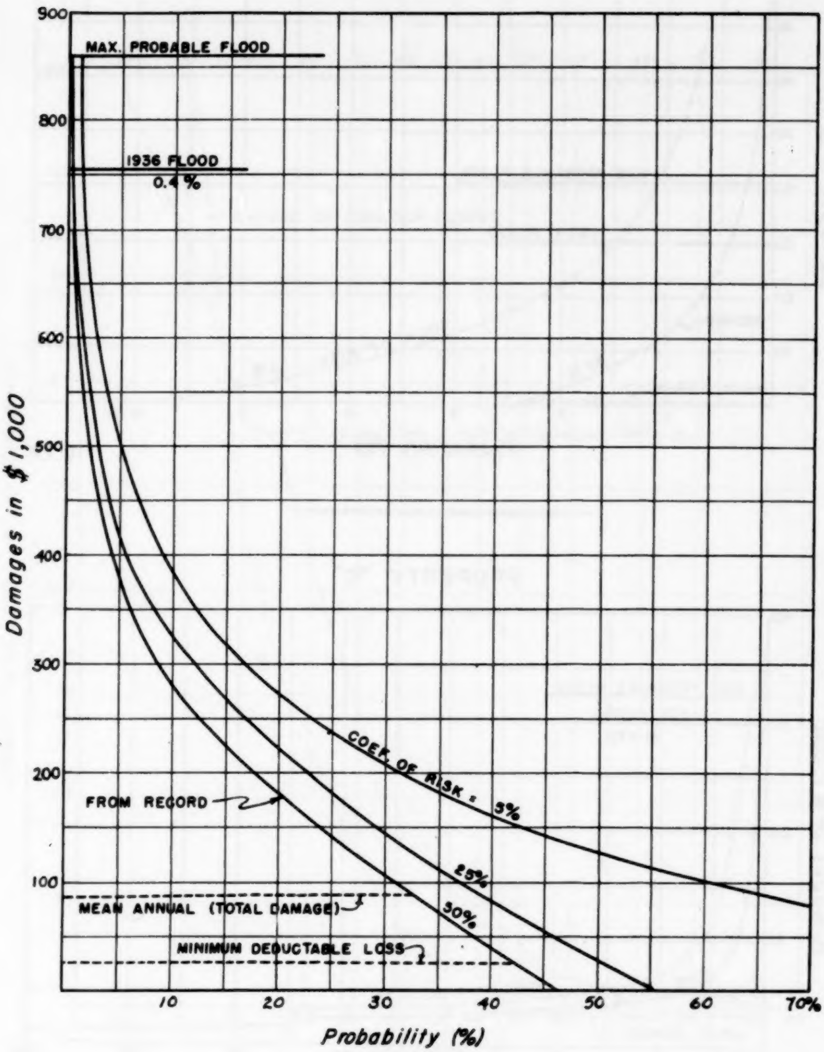


fig.7a

DAMAGE VS. PROBABILITY

PROPERTY "B"

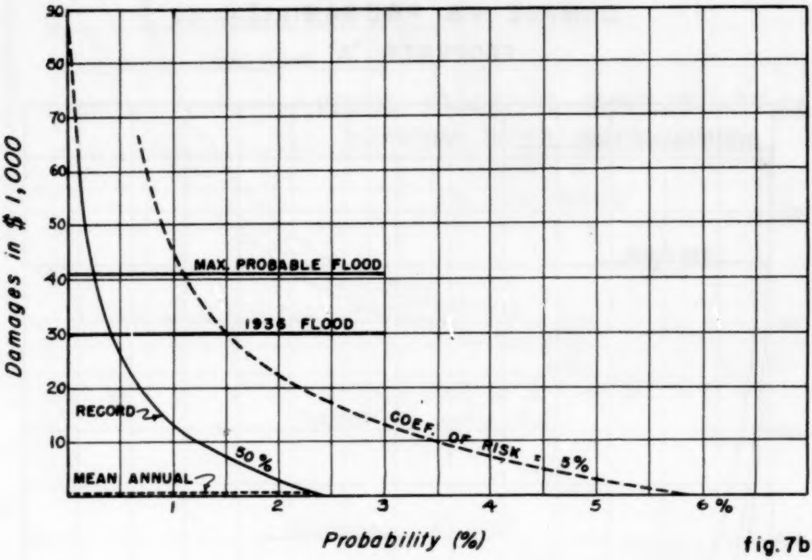


fig. 7b

PROPERTY "C"

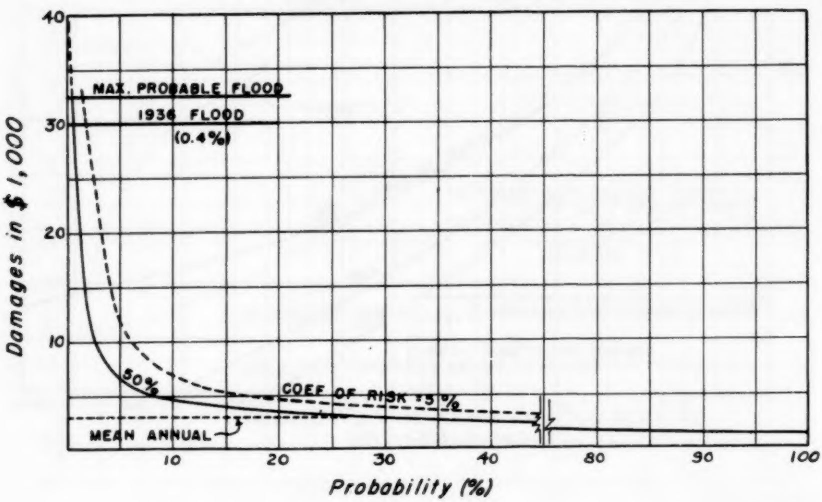
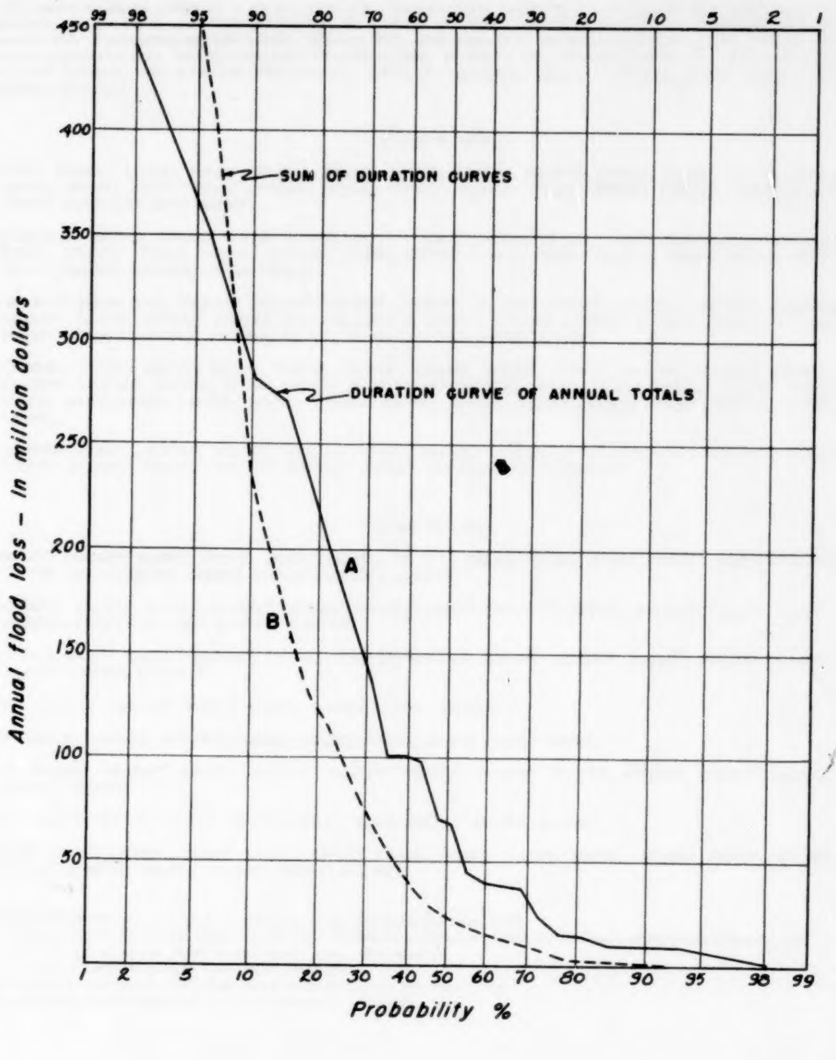


fig. 7c

ANNUAL FLOOD LOSS IN U.S.
U.S. WEATHER BUREAU STATISTICS
1925 - 1948



PROCEEDINGS-SEPARATES

The technical papers published in the past year are presented below. Technical-division sponsorship is indicated by an abbreviation at the end of each Separate Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways (WW) divisions. For titles and order coupons, refer to the appropriate issue of "Civil Engineering" or write for a cumulative price list.

VOLUME 79 (1953)

AUGUST: 230(HY), 231(SA), 232(SA), 233(AT), 234(HW), 235(HW), 237(AT), 238(WW), 239(SA), 240(IR), 241(AT), 242(IR), 243(ST), 244(ST), 245(ST), 246(ST), 247(SA), 248(SA), 249(ST), 250(EM)[a], 251(ST), 252(SA), 253(AT), 254(HY), 255(AT), 256(ST), 257(SA), 258(EM), 259(WW).

SEPTEMBER: 260(AT), 261(EM), 262(SM), 263(ST), 264(WW), 265(ST), 266(ST), 267(SA), 268(CO), 269(CO), 270(CO), 271(SU), 272(SA), 273(PO), 274(HY), 275(WW), 276(HW), 277(SU), 278(SU), 279(SA), 280(IR), 281(EM), 282(SU), 283(SA), 284(SU), 285(CP), 286(EM), 287(EM), 288(SA), 289(CO).

OCTOBER:[b] 290(all Divs), 291(ST)[a], 292(EM)[a], 293(ST)[a], 294(PO)[a], 295(HY)[a], 296(EM)[a], 297(HY)[a], 298(ST)[a], 299(EM)[a], 300(EM)[a], 301(SA)[a], 302(SA)[a], 303(SA)[a], 304(CO)[a], 305(SU)[a], 306(ST)[a], 307(SA)[a], 308(PO)[a], 309(SA)[a], 310(SA)[a], 311(SM)[a], 312(SA)[a], 313(ST)[a], 314(SA)[a], 315(SM)[a], 316(AT), 317(AT), 318(WW), 319(IR), 320(HW).

NOVEMBER: 321(ST), 322(ST), 323(SM), 324(SM), 325(SM), 326(SM), 327(SM), 328(SM), 329(HW), 330(EM)[a], 331(EM)[a], 332(EM)[a], 333(EM)[c], 334(EM), 335(SA), 336(SA), 337(SA), 338(SA), 339(SA), 340(SA), 341(SA), 342(CO), 343(ST), 344(ST), 345(ST), 346(IR), 347(IR), 348(CO), 349(ST), 350(HW), 351(HW), 352(SA), 353(SU), 354(HY), 355(PO), 356(CO), 357(HW), 358(HY).

DECEMBER: 359(AT), 360(SM), 361(HY), 362(HY), 363(SM), 364(HY), 365(HY), 366(HY), 367(SU)[c], 368(WW)[c], 369(IR), 370(AT)[c], 371(SM)[c], 372(CO)[c], 373(ST)[c], 374(EM)[c], 375(EM), 376(EM), 377(SA)[c], 378(PO)[c].

VOLUME 80 (1954)

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FEBRUARY: 398(IR)[d], 399(SA)[d], 400(CO)[d], 401(SM)[c], 402(AT)[d], 403(AT)[d], 404(IR)[d], 405(PO)[d], 406(AT)[d], 407(SU)[d], 408(SU)[d], 409(WW)[d], 410(AT)[d], 411(SA)[d], 412(PO)[d], 413(HY)[d].

MARCH: 414(WW)[d], 415(SU)[d], 416(SM)[d], 417(SM)[d], 418(AT)[d], 419(SA)[d], 420(SA)[d], 421(AT)[d], 422(SA)[d], 423(CP)[d], 424(AT)[d], 425(SM)[d], 426(IR)[d], 427(WW)[d].

APRIL: 428(HY)[c], 429(EM)[c], 430(ST), 431(HY), 432(HY), 433(HY), 434(ST).

MAY: 435(SM), 436(CP)[c], 437(HY)[c], 438(HY), 439(HY), 440(ST), 441(ST), 442(SA), 443(SA).

JUNE: 444(SM)[e], 445(SM)[e], 446(ST)[e], 447(ST)[e], 448(ST)[e], 449(ST)[e], 450(ST)[e], 451(ST)[e], 452(SA)[e], 453(SA)[e], 454(SA)[e], 455(SA)[e], 456(SM)[e].

JULY: 457(AT), 458(AT), 459(AT)[c], 460(IR), 461(IR), 462(IR), 463(IR)[c], 464(PO), 465(PO)[c].

AUGUST: 466(HY), 467(HY), 468(ST), 469(ST), 470(ST), 471(SA), 472(SA), 473(SA), 474(SA), 475(SM), 476(SM), 477(SM), 478(SM)[c], 479(HY)[c], 480(ST)[c], 481(SA)[c], 482(HY), 483(HY).

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a. Presented at the New York (N.Y.) Convention of the Society in October, 1953.
b. Beginning with "Proceedings-Separate No. 290," published in October, 1953, an automatic distribution of papers was inaugurated, as outlined in "Civil Engineering," June, 1953, page 66.
c. Discussion of several papers, grouped by Divisions.
d. Presented at the Atlanta (Ga.) Convention of the Society in February, 1954.
e. Presented at the Atlantic City (N.J.) Convention in June, 1954.